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Aggressive Water
Assessing the Extent of the Problem

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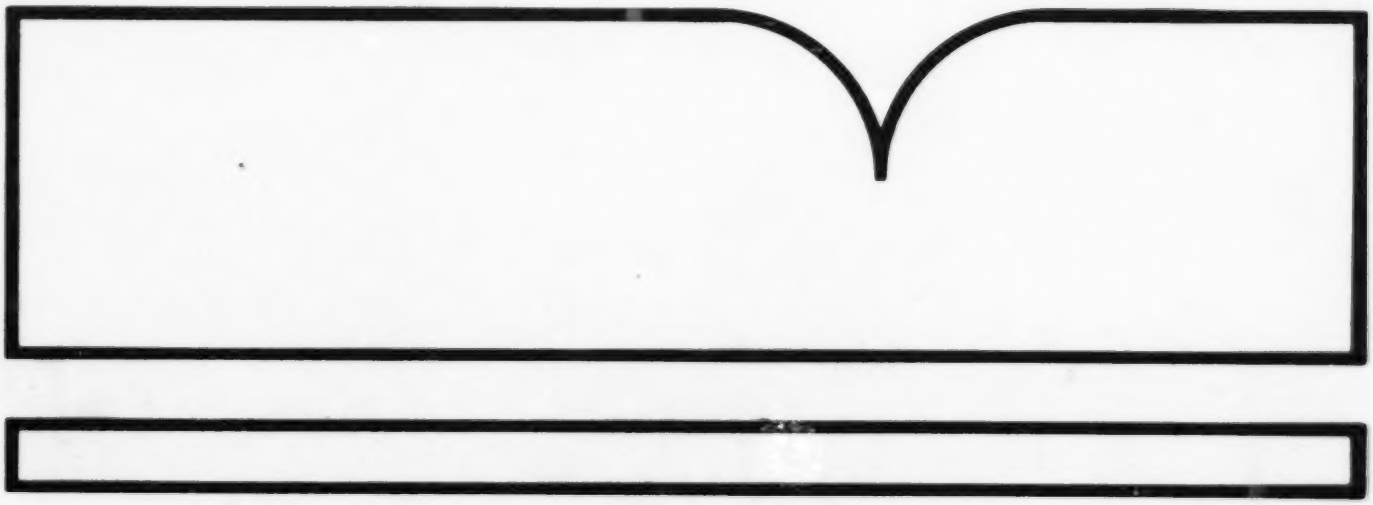

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16. ABSTRACT

That corrosion caused by aggressive water not only carries the threat of distribution system deterioration but also poses a potential health hazard is generally recognized. But just how widespread is the problem? And how serious? A national survey covering water suppliers serving approximately one fifth of the US population shows almost 70 percent of the representative utilities to have moderately to highly aggressive waters.

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Aggressive Water: Assessing the Extent of the Problem

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Michael F. Pansing, Edward C. Hansen, and Patrick J. Clark

That corrosion caused by aggressive water not only carries the threat of distribution system deterioration but also poses a potential health hazard is generally recognized. But just how widespread is the problem? And how serious? A national survey covering water suppliers serving approximately one fifth of the US population shows almost 70 percent of the representative utilities to have moderately to highly aggressive waters.

The corrosion potential (aggressiveness) of drinking water is an important factor in water distribution systems from the viewpoint of consumer health.

Craun and McCabe[1] have suggested that corrosion of distribution and household plumbing contributes to the metal content of drinking water, which may be related to cardiovascular disease rates. Highly aggressive water flowing through asbestos-cement pipes can cause asbestos fibers to be released into the water. The possible relationship between ingested asbestos fibers and cancer is currently under study.

The extent to which corrosive water is a problem in US water distribution systems is difficult to assess. However, water sampling and analysis done by EPA in conjunction with a nationwide health survey has recently provided data that make it possible to calculate several aggressiveness indexes of the drinking water in representative areas of the US before it comes in contact with the distribution system and plumbing. It is also possible to estimate the proportion of utilities in the country with aggressive water.

Water samples were collected as part of a cooperative study with the National Heart, Lung, and Blood Institute, the National Center for Health Statistics, and the Bureau of the Census which involved a health and nutritional survey in 35 geographically distributed areas in the US. The sample areas were randomly selected by the Bureau of Census to be representative of the US population. The 35 areas or primary sampling units (PSUs) were selected from among approximately 1900 PSUs into which the geographic territory of the mainland US has been divided (Fig. 1). Each PSU consists of a county or small group of contiguous counties. For purposes of the health survey the PSUs were stratified into groups by population size, and the 35 locations were chosen so as to include a defined proportion of large metropolitan areas as well as less populated regions. Details of the stratification and selection of primary sampling units can be found in reference 2.

In each area a random sample of water suppliers was selected. The sampling plan included, at a minimum, the following number of water suppliers from the available size categories:

1. All suppliers that serve 100 000 or more people
2. Two suppliers that serve 50 000–99 999 people
3. One supplier serving fewer than 50 000 people.

More than 1300 water samples were collected from 130 utilities in the 35 areas. These were analyzed by the EPA for several water quality parameters and 75 metals. The aggressiveness indexes were computed for each sample. The 130 utilities serve over 40 million people, approximately one fifth of the US population.

Aggressiveness Index (AI)

The aggressiveness of water is defined in the foreword to the AWWA Standard for Asbestos-Cement Distribution Pipe[3] approved January 30, 1977, by the AWWA Board of Directors as

1. Highly aggressive: $pH + \log_{10}(AH) \leq 10.0$
2. Moderately aggressive: $pH + \log(AH) = 10.0\text{–}11.9$
3. Nonaggressive: $pH + \log(AH) \geq 12.0$

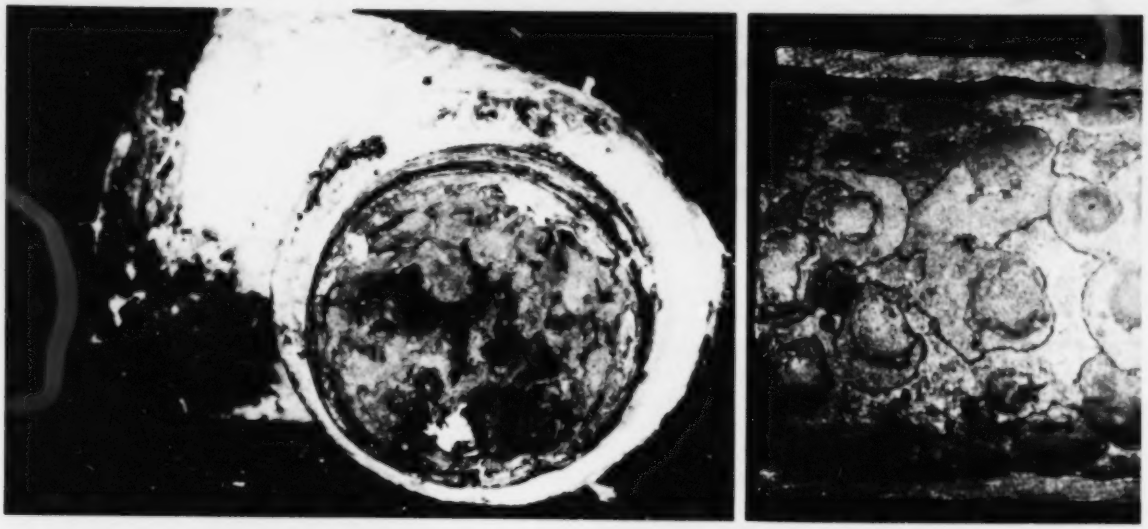
where A = total alkalinity in mg/L $CaCO_3$ and H = calcium hardness as mg/L $CaCO_3$.

According to Standard C400-77, it is recognized that water with a $pH + \log_{10}(AH)$ less than or equal to 10 is extremely aggressive and would be very corrosive to almost all materials found in a typical water system, including the plumbing in consumers' homes.

A comparison of the average aggressiveness indexes of utility waters from representative areas of the US is given below and shown in histogram form in Fig. 2.

Highly aggressive	16.5 percent
Moderately aggressive	52.0 percent
Nonaggressive	31.5 percent

The data show that two thirds of the utilities repre-



sentative of US water supplies had what is considered to be aggressive water by the AWWA C400-77 Standard. The mean aggressiveness index was 11.1; the median value was 11.3. The AI values ranged from 7.5 to 13.3 It is important to note that while the aggressiveness index is a measure of water corrosiveness it does not take into account the use of corrosion inhibitors such as the various divalent metallic phosphates.

A survey of the literature by Merrill and Sanks[4] suggests that the characteristics of a well-conditioned (oversaturated) water include

1. An oversaturation of $CaCO_3$, with a $CaCO_3$ precipitation potential of 4–10 mg/L
2. Calcium and alkalinity values of at least 40 mg/L as $CaCO_3$, with calcium and alkalinity present in approximately equal concentrations
3. An alkalinity to ($Cl^- + SO_4^{-2}$) ratio of at least 5:1 with all concentrations expressed as $CaCO_3$
4. pH in the range of 6.8–7.3. (The pH range 8.0–8.5 should be avoided.)

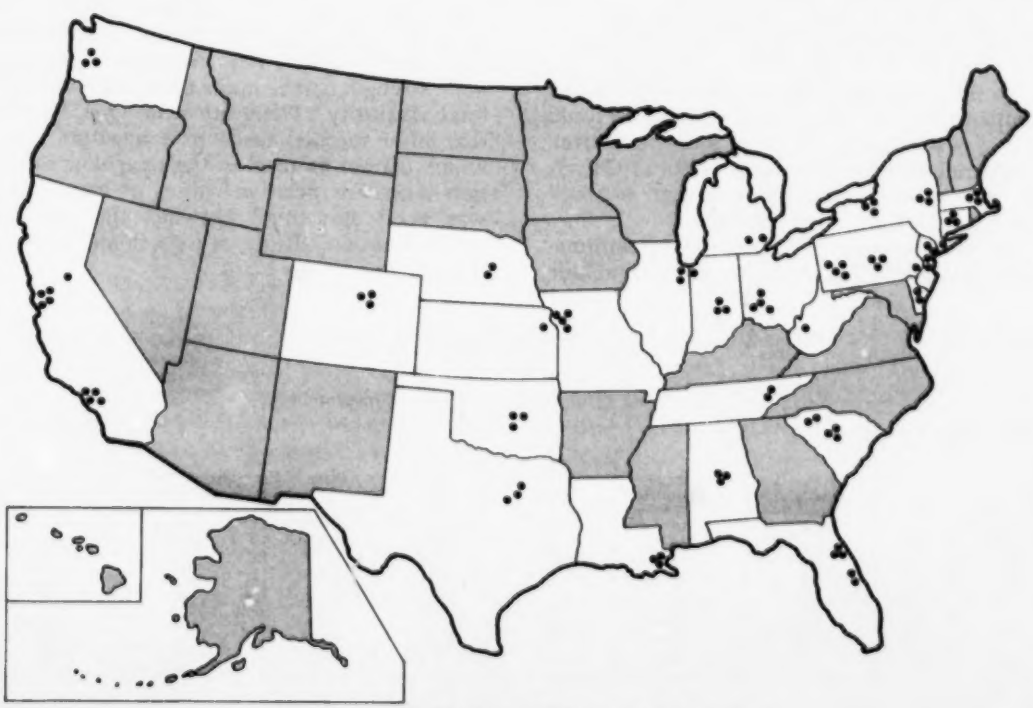


Fig. 1. Geographic Distribution of Primary Sampling Units

Merrill and Sanks concluded that some of the conditions might be mutually exclusive and that the ideally conditioned water as represented by conditions 1, 2, 3, and 4 might be sometimes impossible to prepare. Condition 4 can be preserved only when the untreated water is initially high in calcium and alkalinity.

Of the representative utilities surveyed, none had water in which both the alkalinity and calcium hardness values were over 40 mg/L and the pH was between 6.8 and 7.3.

Figure 3 shows that 10.5 percent of the utilities have pHs in the range 6.8–7.3, while 14 percent had pH values in the range 8.0–8.5. According to Merrill and Sanks, the pH range 8.0–8.5 has less ability to absorb excess acid and base caused by the corrosive process. Outside this range the water's absorption or neutralizing ability is better and it is more protective.

For cement systems, however, there seems to be little need to avoid the pH ranges 8.0–8.5. Also, for cement pipe the third factor, maintaining a minimum alkalinity to $(Cl^- + SO_4^{-2})$ ratio, is not important since there is no need to maintain the passivating properties of protective oxide films in cement systems.[4]

Fifty-five percent of the utilities met condition 2 and had water with both calcium and alkalinity concentrations of more than 40 mg/L. Figures 4 and 5 show the distribution of average alkalinity and calcium hardness values for the utilities sampled.

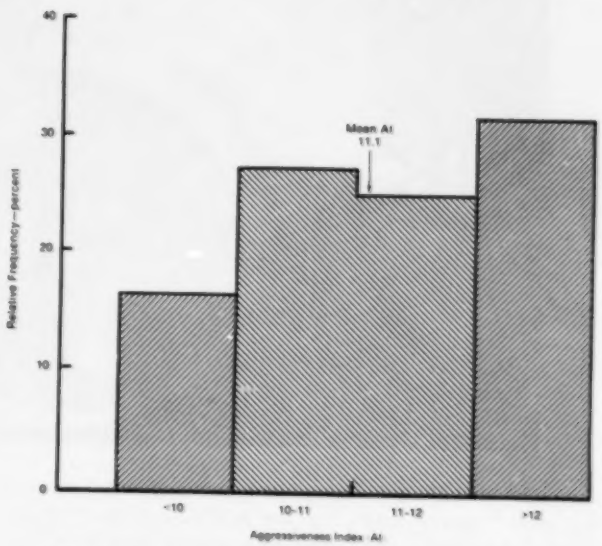


Fig. 2. Histogram of Aggressiveness Indexes (AI) From Representative US Water Utilities

Langelier Index

In 1936 W.F. Langelier[5] described a saturation index based on readily determined parameters which has been used extensively in estimating the corrosion potential of water. The basic equations are

$$\text{saturation index (SI)} = \text{pH actual} - \text{pH saturation}$$
$$\text{pH saturation} = (pK'_2 - pK'_s) + pCa^{++} + pALK + S$$

where $(pK'_2 - pK'_s)$ = dissociation constant estimates based on temperature and total dissolved solids or ionic strength, $pCa^{++} = -\log$(calcium ion in moles per litre), $pALK = -\log$(total alkalinity in equivalents of $CaCO_3$ per litre), S = salinity correction term[6] = $2.5\mu^{1/2}/(1 + 5.3\mu^{1/2} + 5.5\mu)$, and μ = ionic strength.

Because the water quality data obtained in conjunction with the nationwide health survey did not include a total dissolved solids (TDS) determination or data on all ionic constituents, the ionic strength was estimated from the specific conductance (in μS/cm). Betz[7] suggests that for most natural waters a conversion of a microSiemen equivalent to 0.9 mg/L dissolved solids is appropriate. For total dissolved solids contents less than 500 mg/L, the ionic strength may be estimated by $2.5 \times 10^{-5} \times$ TDS.[5] An alternate approximation of ionic strength can be made using the total hardness and total alkalinity.[8] There are situations, however, where this latter method leads to a negative ionic strength which cannot be used in the Langelier salinity correction term. For positive values of ionic strength there was good agreement between the two methods of approximation. Table 1 lists some of the data for comparison.

TABLE 1
Selected Water Quality Data and Index Calculations

Observation Number	Calcium Ion mg/L	pH	Hardness mg/L $CaCO_3$	Alkalinity mg/L $CaCO_3$	Specific Conductance (SPCD) μS/cm	Ion Strength 1*	Ion Strength 2†	Aggressiveness Index	Langelier Saturation Index	Ryznar Index
1	12.79	7.5	84	44	153	0.00044	0.00344	10.85	−1.32	10.1
4	13.35	8.0	82	38	138	0.00311	0.00340	11.06	−0.98	9.8
21	16.0	7.3	48	44	177	0.0040	0.0030	10.5	−1.45	10.2
26	4.4	6.4	25	10	63	0.0014	0.0018	8.4	−3.40	13.2
31	4.2	6.1	18	3	63	0.0014	0.0014	7.8	−4.24	14.0
75	18.0	7.0	60	18	255	0.0053	0.0044	9.9	−2.13	11.3
130	58.0	8.0	222	126	690	0.0108	0.0152	12.2	−0.13	8.3
211	2.0	7.4	12	20	77	0.0017	0.0085	8.4	−2.47	12.3
234	32.0	8.5	98	30	244	0.0053	0.0060	12.1	+0.01	8.5

*0.9 × SPCD × 2.5 × 10^{-5}
†‡ Hardness – Alkalinity (hardness in moles of $CaCO_3$ per litre, alkalinity in equivalent of $CaCO_3$ per litre)

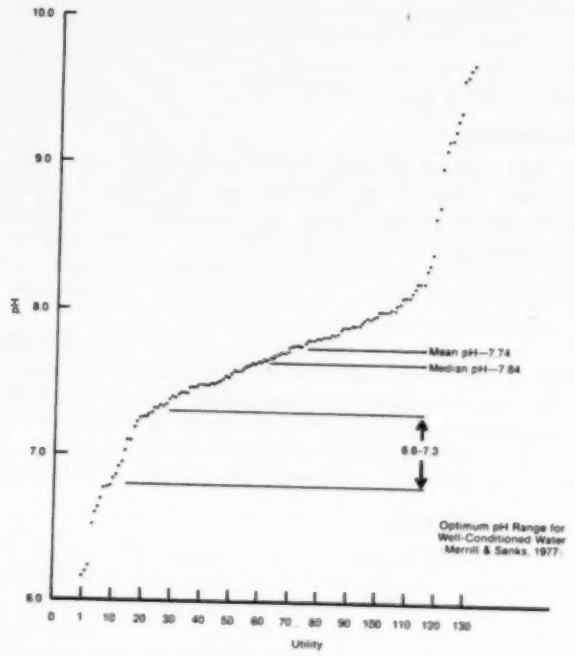


Fig. 3. Representative US Utilities Ranked by pH of Water

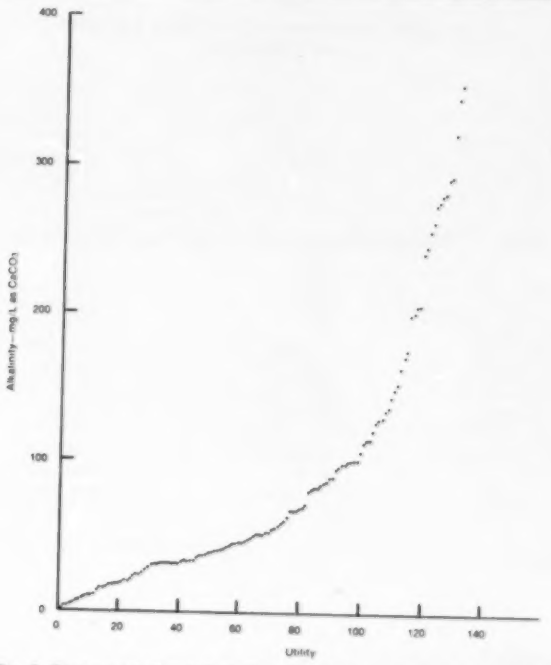


Fig. 4. Representative US Utilities Ranked by Alkalinity of Water

The Langelier saturation index (LSI) is a measure of the degree of calcium carbonate saturation in the water. If the index is zero, the water is in equilibrium. A positive index indicates oversaturation and a tendency to lay down a protective coating in the pipe, and a negative index indicates undersaturation or a tendency to be aggressive to the pipe interior. The greater the negative value, the greater the aggressiveness.

The aggressiveness index (AI) is a simplification of the Langelier saturation index. It uses average temperature and ionic strength factors, and the value of 12.0 is used for water in equilibrium instead of zero as used in the LSI. A comparison between the AI and LSI values showed good agreement. When the LSI was below −2.0, indicating a very aggressive water, the AI was below 10.0. When the LSI was above zero—i.e., nonaggressive—the AI was over 12.0, also nonaggressive.

The mean value of the Langelier indexes for the representative utilities was −1.17. In the 1936 work of Langelier,[5] the average saturation index of the several largest unadjusted municipal water supplies in the US was found to be −1.58.

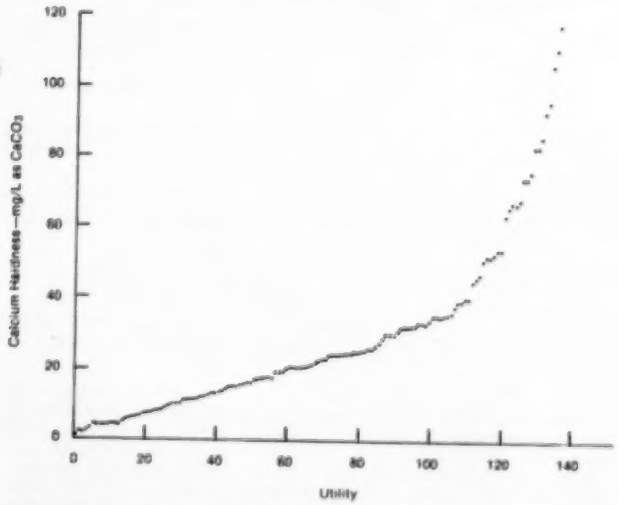


Fig. 5. Representative US Utilities Ranked by Average Calcium Hardness of Water

The Ryznar Index

A stability index (RI) was developed by Ryznar[6] using the same parameters as the Langelier saturation index. Its purpose was to give a quantitative index of the amount of calcium carbonate scale that would be formed and to predict the corrosiveness of waters that are nonscale-forming. The equation is given by

$$RI = 2\ pH\ saturation - pH\ actual$$

where pH actual and pH saturation are defined as in the preceding section on the Langelier index.

The Ryznar index can also be given as

$$RI = pH\ actual - 2\ LSI$$

Field results described by Ryznar show that corrosion occurred in cold water mains when the RI was aboye 8.5. A comparison between the AI and RI showed some agreement. When the AI was below 10 (highly aggressive), the RI was above 10.0. The data show that 20 percent of the utilities representative of the US water supplies have average Ryznar indexes above 10.0, indicating very aggressive water.

Fig. 6. Elements Present in Less Than 1 Percent of Water Samples[10]

Tungsten	Platinum	Indium
Thallium	Rhenium	Tellurium
Germanium	Silicon	Cesium
Ytterbium	Iridium	Zirconium
Thorium	Palladium	Radium

Fig. 7. Elements Not Detected in Any Water Samples[10]

Niobium	Cerium	Argon
Thulium	Tantalum	Gadolinium
Actinium	Neptunium	Polonium
Scandium	Praseodymium	Terbium
Lanthanum	Plutonium	Astatine
Ruthenium	Neodymium	Dysprosium
Rhodium	Osmium	Radon
Lutetium	Promethium	Krypton
Protactinium	Samarium	Holmium
Xenon	Gold	Francium
Halfnium	Europium	Erbium

Metals

Frequency of occurrence and concentration statistics of various elements found in 3834 tap water samples collected in the areas served by the 130 water utilities are given in Table 2. Elements present in less than 1 percent of the water samples are listed in Fig. 6 and elements not detected in any water samples are listed in Fig. 7. Although samples of water from the utilities were also tested for the metals, the data describing how the metal content changed from utility to consumer tap are not yet available. The data are currently being statistically analyzed by computer and will be reported on at a later time. Correlations between metal concentration changes and the aggressiveness index of the utility water are also being made.[10]

TABLE 2
Concentrations of Various Elements in Sampled Water Supplies[10]

Element	Areas With Levels Above Detection Limits	Distribution of Mean Concentrations		
	percent	Maximum µg/L	Minimum µg/L	Mean µg/L
Iron	100.00	1564.3	48.9	244.44
Zinc	98.79	1315.9	27.6	244.73
Copper	96.67	436.7	10.6	150.17
Barium	94.29	358.0	9.4	67.25
Lead	89.83	32.3	2.0	8.305
Manganese	84.14	152.6	2.6	30.89
Arsenic	66.77	7.9	.76	2.372
Cadmium	35.16	8.8	.88	1.814
Chromium	29.22	8.0	.43	1.704
Selenium	9.81	6.6	1.0	3.481
Silver	2.50	112.7	3.3	1.728
Mercury	0.86	268.39	1.0	34.74
Strontium	99.82	672.0	12.5	210.94
Sodium	99.79	79 734	4030.8	27 734
Potassium	99.43	8278.2	720.8	2150.4
Calcium	99.93	120 568	1922.0	32 503
Nickel	83.12	5.1	.4	2.07
Rubidium	60.46	19.0	.3	2.17
Molybdenum	30.10	52.7	1.1	8.05
Tin	28.90	4.0	.9	1.98
Vanadium	29.03	35.0	1.3	4.85
Antimony	18.48	4.0	.8	1.97
Titanium	11.29	4.3	.4	1.20
Cobalt	9.81	106.9	2.0	21.05
Gallium	5.16	35.3	3.5	15.90
Uranium	4.96	1.3	.2	.65
Bismuth	1.43	6.5	.3	1.97

Conclusions

1. Analyses of drinking waters from utilities in areas randomly selected by the Bureau of Census to be representative of the US population indicate that 16–18 percent of the utilities in the US have "highly aggressive water" that should be very corrosive to almost all pipes found in a typical water system and may contribute metals or asbestos to the drinking water.

2. On the basis of the analysis of more than 1300 water samples from utilities in 35 representative areas in the US, the aggressiveness index (AI)[9] is easier to compute than the Langelier saturation index and is its equivalent in indicating whether a drinking water is aggressive in terms of calcium carbonate saturation.

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